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EVALUATION OF REMOTE SENSING IN CONTROL
OF PINK BOLLWORM IN COTTON

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16. Abstract The main objective of this investigation is to evaluate the use of a satellite in monitoring the cotton production regulation program of the State of California as an aid in controlling pink bollworm infestation in the southern deserts of California. Color combined images of ERTS-1 multispectral images simulating color infrared are being used for crop identification. The status of each field (i.e., crop, bare, harvested, wet, plowed) is mapped from the imagery and is then compared to ground survey information taken at the time of ERTS-1 overflights. A computer analysis has been performed to compare field and satellite data to a crop calendar. Correlation to date has been 97% for field condition. Actual crop identification varies; cotton identification is only 63% due to lack of full season coverage.					
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PREFACE

The objective of our study was to evaluate ERTS-1 imagery for the identification and mapping of cotton fields in the southern deserts of California. If successful in terms of accuracy, cost, and timeliness, a new tool would be available to the State of California in its effort to control pink bollworm infestation of cotton. Our investigation proved to be less costly; accuracy was less than field mapping, but due to the facts that a full cotton season was not available and time was needed for the development and implementation of the computer system, timeliness was poor. Data was received 45 to 60 days after a given satellite pass; a maximum of two weeks delay is necessary if the program is to be successfully utilized. Recommendations include increased resolution of ERTS-1 imagery, a longer study period (at least one full cotton season), and imagery receipt no later than two weeks after a satellite overpass.

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INTRODUCTION

The identification of crops from high altitude or space photography has been long considered important for such purposes as land use mapping, crop yield prediction, disease identification, control, and eradication, and crop inventory. The main objective of this investigation is to evaluate the use of satellite imagery in monitoring the cotton production regulation program of the State of California as an aid in controlling pink bollworm infestation in the southern deserts. It should be stressed that this is only the initial and most obvious objective. If the proposed investigation is successful, the potential of such a satellite monitoring program for agriculture is unlimited.

The three main agricultural areas in the southern deserts of California, the Imperial, Coachella and Palo Verde Valleys, are heavily infested with pink bollworm which affects both the quantity and quality of cotton produced. Therefore, the State of California has established regulations in an attempt to control the expansion in numbers and areal extent of the pink bollworm. The regulation states that all acreage to be planted to cotton must adhere to the following rules. Cotton may not be planted in the Coachella and Palo Verde Valleys until February 28, and February 15 in the Imperial Valley. By December 15, all cotton fields must be picked, all remaining plant material must be thoroughly shredded and subsequently plowed underground. Those fields must then be left fallow until the following February unless another crop besides cotton is to be planted in those fields. The "plowdown" procedure is to insure that any pink bollworm in the larval or diapause state will have not cotton plant material on which to feed during the winter months.

The most immediate potential exists in the cooperative regulation of cotton production between California, Arizona, and Mexico. Substantial areas

of cotton exist in the Arizona area bordering the southern California deserts and in the areas of Mexico bordering the southern California deserts. Both of these areas represent substantial sources of pink bollworm infection for California. Therefore, if the management system imposed upon cotton producers by the California Department of Agriculture is not successful, it will be imperative to determine whether the lack of success is due to the failure of growers in California to comply with the regulations or the fact insects are entering the diapause in readily available sources of plant material in Mexico and Arizona and then spreading into the southern California area.

Another application of this research could be the extension of such a management system employing satellite monitoring to other crops in California and the rest of the United States. The use of chemical pesticides for the control of insects is coming under increasing criticism, and it is recognized by scientists the world over that other means of control must be utilized whenever possible. One means of control is that of pest management, i.e., the kind of improved management that we are attempting to develop in the cotton fields of the southern California deserts. There are many other instances of crop production in the United States, indeed the world, where insect control could be improved by removing a crop before an insect pest enters the diapause stage. Whenever such programs involve substantial acreage, the assurance that growers are cooperating in observing a regulatory schedule is imperative. The use of satellite sensing devices to provide such grower assurance could easily prove to be the simplest means of monitoring available.

Furthermore, the investigation might also play a significant role in averting a far greater disaster than the current pink bollworm threat to cotton crops in southern California. Although the California desert areas produce 80,000 acres of cotton annually, the State of California in its entirety produces over 900,000 acres of cotton, the bulk of which is

concentrated in the San Joaquin Valley. It is a major effort of the Federal government, the California Department of Agriculture, and the University of California to insure that pink bollworm does not spread into this area of cotton productions. Although such a disaster has not occurred, pink bollworms have been found in the San Joaquin Valley and it may become necessary to implement the regulations that have been prepared but not yet practiced. It would become necessary to monitor the defoliation, plowdown and replanting dates for 900,000 acres of cotton rather than 80,000 acres. Obviously, it would be almost impossible to carry out such a massive management program without the development of some remote sensing system.

PROJECT HISTORY

Cotton is regulated by law in California in an attempt to control pink bollworm. The insect is a serious pest in the southern deserts of California because it affects both the quantity and quality of cotton produced. At present, there are no effective chemical means of controlling the pink bollworm, therefore regulations were established to provide a biological control. In order to do this, it is necessary to break the insects' life cycle. The pink bollworm is in the resting or diapause stage during the winter months; however it still needs plant material for food. The regulations, therefore, for the 1972 growing season required that all cotton in the three valleys was to be harvested, all remaining material plowed under, and all gin trash disposed of by December 15. Cotton could not be planted until February 15 in the Imperial Valley and February 28 in the Coachella and Palo Verde Valleys.

Approximately 900,000 acres of cotton are grown annually in California. All cotton in the southern deserts is monitored by ground survey teams which is an expensive and time consuming process. Although the San Joaquin Valley produces almost 90% of the cotton in California, it has not yet been seriously affected by the pink bollworm. However, the insect has been found in this

area and it is imperative that a more efficient and economical means of monitoring cotton be provided.

Because cotton growing is regulated by law and since the Imperial, Coachella, and Palo Verde Valleys, which are heavily infested, are essentially cloud-free throughout the year, it was felt this would provide an excellent opportunity to test the usefulness of sequential photography for crop identification.

As pointed out by Johnson (1969), the only viable means for identifying crops, given present technology, would be sequential photography. The Earth Resources Technology Satellite (ERTS) launched in July, 1972 provided photography for a given area every 18 days. A multispectral scanner (MSS) operating in four spectral bands (.5 - .6 um, .6 - .7 um, .7 - .8 um, .8 - 1.1 um; green red, and two infrared bands respectively) was used to obtain the imagery.

The study sites for our project are the southern deserts of California. Our purpose was to determine whether or not cotton in the Imperial, Coachella, and Palo Verde Valleys could be identified (Fig. 1, 2). Because cotton is regulated by law in California isn an attempt to control pink bollworm, and because these areas are essentially cloud-free throughout the year, it was felt these areas would provide a good test for crop identification using sequential photography.

Two basic methods were used to identify cotton fields. In the Imperial Valley, the imagery, which was combined to simulate color infrared (CIR), was mapped every 36 days and each field was classified as bare, wet, plowed, harvested, or cropped. At the time of the ERTS overflight, a field survey was conducted. The information obtained from the imagery in addition to field size, time of year, and the crop calendar for the Imperial Valley were then fed to a computer which determined what crops would most likely be in a given field at a particular time. The data were then checked against the field

survey for accuracy. After one year of study, it was found that the accuracy for field condition identification of a given field on a given date is 92%. After four consecutive dates, the accuracy rises to 97% for field condition identification. Computer identification accuracy for specific crops varied, e.g. sugar beets, 82%, cotton, 63%.

In the Coachella and Palo Verde Valleys, all fields which were bare in March were mapped. Cotton is not planted in these areas until February 28 and would not begin to appear on the imagery until May or June. The imagery was mapped again in May to determine which fields showed a crop. A field survey of the two valleys was conducted in August to determine the accuracy of the crop mapping. The results were poor; approximately 50% of the fields mapped from the imagery were correctly identified. The same method was used in the Imperial Valley as a check. The accuracy was only 33%.

The poor results obtained from the bare field method and the variability of specific crop identification were due in large part, we feel, to the poor resolution of the ERTS-1 imagery and because two incomplete seasons, July to December, 1972, and March to May, 1973, are hardly adequate to determine the usefulness of the system. At the minimum, one full year covering the entire cotton season is needed in order to obtain meaningful results. Three years would be preferable in order to minimize factors affecting identification such as weather, crop conditions, and operator inexperience. We feel strongly that our computer system and sequential photography are capable of identifying crops with great accuracy, but only if they are supported with better camera systems and a minimum study period of one to three full years of the entire cotton season.

PROJECT SYSTEMS AND RESULTS

Base maps.

→ The first requirement for our study was a set of base maps for each of the three valleys to be studied. A base map of the Imperial Valley had already been prepared by Claude Johnson, Department of Earth Sciences, Geography, University of California, Riverside. The scale of the map is 1:63,360. Base maps for the Coachella and Palo Verde Valleys were obtained from the Agricultural Commissioner's office in each valley. The respective scales are 1:36,115 and 1:31,680. All base maps were transferred onto opaque acetate for mapping purposes. It should be noted here that a base map prepared from a USGS topographic map can be overlaid directly onto an ERTS-1 image with little distortion (Fig. 3).

Underflight imagery.

The U-2 underflight imagery because of its high resolution, was used to update field lines on all maps. It was also extremely useful as a check on information mapped from the ERTS-1 images. Although the color balance on the U-3 photography varied, it nonetheless proved very useful in detecting the various stages of the cotton plowdown (Fig. 3) where were not visible on the ERTS-1 images. The U-2 imagery was not studied intensively as to its full value for our study, we believe that results for both the "bare field" and crop calendar method would have been better had we utilized it, primarily because of the high resolution.

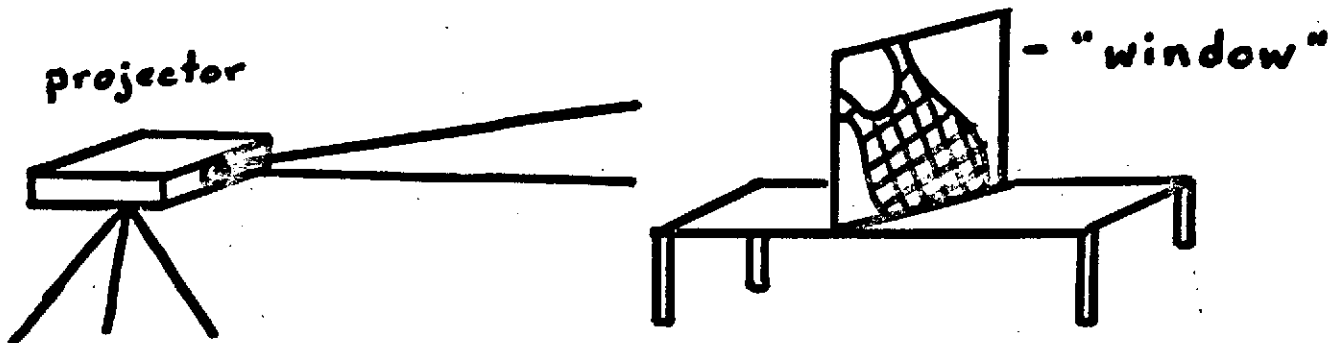
Color images.

→ In order to obtain information for our project, it was important to have color images. The first method used was the Diazochrome process in which bands 4, 5, and 7 from the multispectral scanner (MSS) were copied to yellow, magenta, and cyan respectively, then superimposed to simulate CIR. This is an adequate "first look" procedure, but the colors vary considerably from one pass to another and do change over time.

The Department of Earth Sciences, Geography, University of California, Riverside, received an International Imaging Systems (I²S) optical color combiner in January, 1973. Through their cooperation, we were able to obtain high quality, CIR photographs. The photographs are 35mm slides of the images projected onto the viewing screen of the color combiner.

Information mapping.

In order to map information, the slides are projected onto a clear plate glass "window" on which has been placed an opaque acetate base map of the area. By using this method, the operator can then map the information directly from the back of the window and not interfere with the projected image (Fig. 4). Since the projector and "window" are both movable, this allows the image to be projected at any scale needed for mapping.



Two methods were used to identify cotton fields in the Imperial, Coachella, and Palo Verde Valleys. The "bare field" method was used in all three valleys and the detailed crop calendar method accounting for all crops was used in the Imperial Valley.

"Bare field" method.

→ The "bare field" method is based on the theory that no cotton remains in any field after December 15 and cannot be planted until February 15 in the Imperial Valley and February 28 in the Coachella and Palo Verde Valleys. Therefore, all bare fields evident in January and February photography could potentially be cotton fields and would be mapped as such. Irrigation would begin in late February and early March and cotton would begin to appear on

the imagery in April. Although such crops as sorghum, sudan grass, tomatoes, corn, and onions are planted about the time cotton is, these crops would mature more rapidly and be harvested long before cotton, thereby eliminating these fields.

Unfortunately, the winter of 1972-73 was an extremely wet one and not all cotton was plowed under by December 15. Also, fields which would normally have shown bare in January and February often looked irrigated and heavy weed growth made fields look cropped when they actually were not. The rains also delayed the planting of cotton, so some fields did not show a crop until midsummer and were not mapped as cotton.

Rather than using January and February photography, it was decided that the March imagery would be mapped for bare fields. These were then checked against May photography in order to determine which fields had begun to show a crop. Since there was no photography after May 23, all bare fields which had become cropped were assumed to be cotton since there was no way to eliminate the other crops previously mentioned. A field survey of all three valleys was conducted in August to check the accuracy of the maps made from ERTS-1 imagery.

The results were as follows. In the Coachella Valley, no fields which were predicted to be cotton were cotton. The Imperial Valley was better with a 33% accuracy. Fifty percent accuracy was achieved in the Palo Verde Valley. The results are poor and hardly meaningful because there was no imagery after May 23 and a full cotton season was not available for study.

Crop calendar method.

→ The Imperial Valley was studied in cooperation with the Department of Earth Sciences, Geography, University of California, Riverside. The method used was based on the crop calendar for all crops grown in the valley. The ERTS-1 imagery was mapped every 36 days (alternate passes of the satellite) and field surveys were conducted in the valley at 36 day intervals to coincide with the

ERTS-1 passes. Mapping consisted of classifying each field according to its conditions, i.e., bare, wet, plowed, harvested, or cropped. Using the color combined CIR photographs, the respective colors for each of the above conditions were white, blue or dark lavender, gray brown or light lavender, yellow, and red. Differentiation between wet and plowed was often a problem and heavy weed growth due to the rains also caused problems in classifying cropped fields.

The information obtained from the photography in addition to field size, time of year, and the crop calendar for the valley, were then given to a computer which determined statistically which crop(s) was (were) most likely to be in a given field at a particular time. This information was then checked against the field survey data for accuracy. The correlation for field condition over four 36 day cycles has been 97%; crop identification accuracy varies from 82% for sugar beets to 63% for cotton. The low accuracy for cotton is due to the fact that a full cotton season could not be studied and the result should not be considered meaningful.

Monitoring Crop Changes in the Imperial Valley from ERTS-1.

Claude W. Johnson, Department of Earth Sciences, Geography, University of California, Riverside.

Sequential satellite imagery can provide sufficient data to determine specific field conditions with 97% accuracy. Techniques being developed at the University of California, Riverside, utilize the color infrared returns from an ERTS-1 color combined image of multispectral bands 4, 5, and 7. Combining the interpretation procedures of the imagery with a computerized program that compares the data to the actual crop calendar of the region, each field of 20 acres or more can be monitored over a minimum of four sequential 36 day cycles and subsequently identified by the computer as to the most probable crop that is growing within that field.

ERTS-1 images of 1972 of 26 August, 1 October, 6 November, and 12 December were interpreted for the experiment and results compared to approximately 10 of the total field population (biased sample) that had been ground surveyed. The results discussed in this report are based on this comparison. Although the ground survey fields were biased by accessibility to hard surfaced roads, the percentage breakdown by total number of crops by field and by acreage are almost identical to the Imperial Irrigation Report percentage breakdown of crops growing as of December 31, 1972. Only four sequential 36 day cycles were used due to the time needed to develop the computer program and because the four fall dates were more likely to provide better field condition information for cotton than the spring and summer dates.

Initial work with specific crop identification involved field condition data from four 36 day cycles between August 26 to December 12, 1972. From the 8,000 plus field in the Imperial Valley, 1,164 fields were studied, and their data used to test different approaches to crop identification. The 1,164 fields used were specifically selected because ground truth surveys were available for these fields, thus making it possible to check tentative conclusions about the crop growing in any one field, and facilitating perfection of the crop identification process. A computer card was made for each field, and each time more imagery was received, the condition of each field was coded and punched on the card.

The Imperial Valley Crop Calendar was used as a guide; however, it was found that the field condition code sequences obtained from ERTS-1 imagery differed from the idealized crop calendar because of the extremely wet fall and winter in the Imperial Valley in 1972. Therefore, it was necessary to depart from the idealized crop calendar. In order to devise a system for crop identification applicable to the time period in question, we examined carefully the code sequences of the sample field, and recorded them. Then

we matched each field's code sequence, ground truth, and acreage. This allowed us to note several trends in the data, and to determine which crops would fit any particular sequence. Two significant things were noted at this time: (1) for any one sequence, crops varied if the field in question was over 80 acres or 80 acres or less, because field crops are more common in fields of over 80 acres, and (2) some crops could not be positively identified from only four periods because of similar code sequences and acreage sizes as other crops.

Steps were taken to incorporate the above two findings into a computer program designed to automatically identify crops from the input data. The first step was to divide fields with a certain sequence into fields with over 80 acres and fields with 80 acres or less. The second step was to establish "weights" relating to the probability of a particular crop growing under any code sequence. The weights were obtained by computing percentages of different crops in each code sequence. For example, a very common code is 1 1 1 1, indicating that the crop in that field was identified on ERTS-1 imagery as growing during each of the four periods considered. We determined that for fields of over 80 acres for that code sequence the weighted values are:

Alfalfa	92	Sugar Beets	3	Cotton	3	Barley	2
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Using only four cycles, uncertainty of identification for some sequences results, for example if the sequence is 1 1 1 2, with 80 acres or less, the identification and weights are:

Alfalfa	40	Cotton	38	Sorghum	13	Sudan Grass	6	Lettuce	3
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In this case, the addition of more code sequences would permit definite identification of the crop.

In the process of reviewing the fields and determining the weights, it became apparent that some codes for no known crops. We designed the computer program to note all the fields with code sequences other than those of known

The irregular code sequences can then be checked to determine if human error in initial interpretation of the imagery occurred, and if so, the error can be corrected, and the code identified. Another possibility with an irregular crop code is that a new crop is being grown, such as was the case with Alicia grass. In a few cases, data was not obtainable from the imagery for certain fields. The crops in these fields, obviously, could not be identified.

With the system outlined above, using only four periods, accuracy of specific crop identification varies. It is not usually possible to state for certain that one particular crop is growing in a field because several crops may have the same code sequence, and four time periods are enough for only preliminary identification of the crop growing in any one field. Our findings suggest that overall, an 81% accuracy can be expected if one accepts the two highest weights of any code sequence. With more sequential imagery interpretation, positive identification of a crop can be anticipated.

The system being developed shows great promise of achieving the objective of more than 90% accuracy of crop inventory for a given agricultural region. The experiment utilized only four 36 day cycles. Many more fields could have been identified if the cycles were extended to at least 6 time frames. More importantly, the system operating throughout the entire year would have the advantage of knowing the previous crop. In the Imperial Valley the previous crop is a great aid to identification and inventory procedures because there are restraints on crop rotation. Sugar beets for example must be planted before cotton has been picked. Therefore, sugar beets cannot follow a cotton crop. Watermelons cannot be planted in the same field for a five year period. Factors such as the above can be very useful in developing an automated crop inventory system. Future investigations should consider performing the task on a year around basis.

COST ESTIMATE

Table I

	Man hours		Cost	
	ERTS-1	Ag.Comm.	ERTS-1	Ag. Comm.
Imperial	161	320	\$ 846.00	\$1,800.00
Coachella	15	120	90.00	600.00
Palo Verde	15	N.D. *	90.00	N.D.
	191 hours	440 hours	\$1,026.00	\$2,400.00

* N.D. - no data

From the table, it is obvious that both time and cost for the ERTS-1 investigation was less than the field surveys conducted by the agricultural commissioners in terms of actual time spent for field and photographic mapping. Approximately \$40.00 was spent on computer time to obtain field condition and crop identification for the four dates used. Even if a full year's coverage were used, the money spent for computer time would not significantly affect the cost savings provided using the ERTS-1 system.

SIGNIFICANT RESULTS

The results obtained from the "bare field" method are obviously poor: 0% accuracy for the Coachella Valley, 33% and 50% respectively for the Imperial and Palo Verde Valleys. There are, however, some mitigating circumstances. Foremost is the fact that neither the 1972 or 1973 photography provided an entire cotton season to study. Cotton fields on the 1972 imagery were located using information obtained from the various agricultural commissioners. There was no accurate way of identifying cotton fields on the 1973 imagery because a full cotton season was not available to study and there was no way to eliminate those crops which appear at the same time as cotton but are harvested earlier. In addition, the heavy winter rains delayed the plow down and planting of cotton and caused problems in attempts to map irrigated and cropped fields.

Because of weather conditions such as this, it is only logical that a study such as this should be carried out over a period of years in order to minimize the effects of such conditions. Also, because no imagery was received after May 23, 1973, there were no means to eliminate other crops which were planted at the same time as cotton, but would be harvested before cotton. Again this shows the necessity for a longer study period, or at least a minimum of one full cotton season.

The computer results were extremely good: 97% accuracy in identification of field condition after four consecutive dates. Actual crop identification varied from 82% accuracy for sugar beets to 63% for cotton. Only four consecutive 36 day cycles, August 26, October 1, November 6, and December 12, 1972, were used. This was due in part to the time needed to develop and implement the computer identification program and because it was felt that this half of the cotton season, which included the plow down, would give the most accurate results. It should be noted, however, that if a full cotton season had been available for analysis, the accuracy for crop identification would no doubt be greater.

The cost estimate has shown that there is a definite advantage to using ERTS-1 information. Lower cost, less time, and equivalent accuracy to field mapping are significant factors in "selling" this type of system to a user. We have achieved lower cost and less time. We believe we can achieve equivalent accuracy. The most significant factor, however, is timeliness. The delay of 45 to 60 days in receiving imagery makes this program of virtually no practical use. For agricultural management, particularly pest management, two weeks is the absolute maximum delay which will provide useful data and results.

By color combining bands 4, 5, and 7 of the MSS to simulate color infrared, we obtained the best color contrasts for field condition identification which

are vital for actual crop identification. Also necessary are field size, time of year, and a crop calendar for the study area.

CONCLUSION.

Pink bollworm infestation in the southern deserts of California is of serious proportions. The costs of surveying cotton fields are such that the agricultural commissioner of the Imperial Valley has eliminated the survey for that valley. The sequential coverage provided by ERTS-1 is shown to be useful in our study to identify and map cotton fields. Although the accuracy for cotton field identification is only 63%, we feel that with at least a full cotton season available for analysis we can achieve equivalent accuracy to field mapping. We have achieved the ability to identify and map cotton fields in less time and with less cost.

The planimetry of the ERTS-1 imagery is such that a base map prepared from a USGS topographic map can be superimposed on the image with almost perfect accuracy. As such, a base map can be drawn directly from ERTS-1 imagery eliminating the need for tedious cartographic work. High flight imagery such as the U-2, if available, can be used for updating field lines which do change and which are not always seen on ERTS-1 imagery. Greater resolution of the ERTS-1 imagery would eliminate the need for high flight photography.

We have found that color combining bands 4, 5, and 7 from the MSS to simulate color infrared provide the best color contrasts for field condition identification which is vital to actual crop identification. In addition, field size, time of year, and a crop calendar of the area to be studied must be available for crop identification.

There are three recommendations which we feel will not only improve our results, but will make crop inventory and management a practical application. First, the camera system must be improved, especially with regard to resolution.

Second, a longer study period is needed to minimize such factors as weather, crop conditions, and operator inexperience. At least one full cotton season is vital to the success of the study. Third, but most important, imagery must be received by the user no more than two weeks after the pass is made. All three recommendations are necessary if the project is to succeed, but only timeliness will prove its worth.

APPENDIX I.

There are several crops and field conditions that can and were confused with cotton in the Imperial Coachella, and Palo Verde Valleys. These are listed below as well as the times they can be eliminated.

<u>Palo Verde</u>	<u>Coachella</u>	<u>Imperial</u>	
sorghum	sorghum	alfalfa	stubble
alfalfa	plowed fields	sudan grass	harvested fields
melons		sorghum	wet leach fields
weeds		asparagus	plowed fields
plowed fields		melons	abandoned fields
		rye	

sorghum - can be eliminated between August and October

sudan - can be eliminated between August and October

melons - fall melons, planted in summer after cotton has matured

melons - spring melons, harvested in June after most cotton has matured

rye - generally a cover crop for alfalfa

alfalfa - can be eliminated only after cotton is harvested or if it is

known that the field is alfalfa and will remain so

asparagus - can be eliminated only after cotton is harvested

abandoned - can be eliminated at first field check

weeds - difficult to eliminate especially if rains are heavy

wet leach - some can be eliminated with first field check, but can occur

during the whole season and may cause problems

stubble and harvested - usually are grain or grass crops; probably showed

this year due to heavy rains (wet ground made color

identification difficult); cotton can be planted through

June and a recently harvested field could look like an

emergent cotton field.

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